COMBINED GEOPHYSICAL INVESTIGATION TECHNIQUES TO IDENTIFY BURIED WASTE IN AN UNCONTROLLED LANDFILL AT THE PADUCAH GASEOUS DIFFUSION PLANT, KENTUCKY

Peter T. Miller
Advanced Geological Services, Inc.
3 Mystic Lane, Malvern, PA 19355

R. John Starmer
PMC Environmental
1700 Rockville Pike, Suite 400, Rockville, MD 20852

ABSTRACT

The primary objective of the investigation was to confirm the presence and determine the location of a cache of 30 to 60 buried 55-gallon drums that were allegedly dumped along the course of the pre-existing, north-south diversion ditch (NSDD) adjacent to permitted landfills at the Paducah Gaseous Diffusion Plant, Kentucky. The ditch had been rerouted and was being filled and re-graded at the time of the alleged dumping. Historic information and interviews with individuals associated with alleged dumping activities indicated that the drums were dumped prior to the addition of other fill materials. In addition, materials alleged to have been dumped in the ditch, such as buried roofing materials, roof flashing, metal pins, tar substances, fly ash, and concrete rubble complicated data interpretation. Some clean fill materials have been placed over the site and graded. This is an environment that is extremely complicated in terms of past waste dumping activities, construction practices and miscellaneous landfill operations. The combination of site knowledge gained from interviews and research of existing site maps, variable frequency EM data, classical total magnetic field data and optimized GPR lead to success where a simpler less focused approach by other investigators using EM-31 and EM-61 electromagnetic methods and unfocused ground penetrating radar (GPR) did not produce results and defined no real anomalies.

A variable frequency electromagnetic conductivity unit was used to collect the EM data at 3,030 Hz, 5,070 Hz, 8,430 Hz, and 14,010 Hz. Both in-phase and quadrature components were recorded at each station point. These results provided depth estimates for targets and some information on the subsurface conditions. A standard magnetometer was used to conduct the magnetic survey that showed the locations and extent of buried metal, the approximate volume of ferrous metal present within a particular area, and allowed estimation of approximate target depths. The GPR survey used a 200 megahertz (MHz) antenna to provide the maximum depth penetration and subsurface detail yielding usable signals to a depth of about 6 to 10 feet in this environment and allowed discrimination of objects that were deeper, particularly useful in the southern area of the site where shallow depth metallic debris (primarily roof flashing) complicated interpretation of the EM and magnetic data.

Several geophysical anomalies were defined on the contour plots that indicated the presence of buried metal. During the first phase of the project, nine anomalies or anomalous areas were detected. The sizes, shapes, and magnitudes of the anomalies varied considerably, but given the anticipated size of the primary target of the investigation, only the most prominent anomalies were considered as potential caches of 30 to 60 buried drums. After completion of a second phase investigation, only two of the anomalies were of sufficient magnitude, not identifiable with existing known metallic objects such as monitoring wells, and in positions that corresponded to the location of alleged dumping activities and were recommended for further, intrusive investigation.

Other important findings, based on the variable frequency EM method and its combination with total field magnetic and GPR data, included the confirmation of the position of the old NSDD, the ability to differentiate between ferrous and non-ferrous anomalies, and the detection of what may be plumes emanating from the landfill cell.
INTRODUCTION

The primary objective of the Old North South Diversion Ditch project was to determine the accuracy of statements eyewitnesses made to Department of Justice investigators that large volumes of potentially contaminated waste materials were placed in the streambed of the old North/South Diversion Ditch north of Ogden Landing Road. The investigation focused on the presence of contaminated materials and did not seek to fully characterize all of the materials in the entire length of the streambed. The geophysical studies described here were designed to support the project and were especially targeted to focus trenching activities on a potential cache of from 30 to 60 steel drums reportedly disposed of at the bottom of the old stream course.

BACKGROUND

The Paducah Gaseous Diffusion Plant (PGDP) is located in rural McCracken County, Kentucky. The center of PGDP is about 10 miles (16 km) west of Paducah, Kentucky, and about 3 miles (5 km) south of the Ohio River (see Figure 1). There are numerous active and inactive production buildings, offices, equipment and materials storage areas, active and inactive waste management units, and other support facilities situated within a fenced security area. The Department of Energy (DOE) owns and directly controls approximately 689 acres as a "buffer zone" and licenses 1986 acres to the Commonwealth of Kentucky as part of the West Kentucky Wildlife Management Area (WKWMA). Three small communities, Heath, Grahamville, and Kevil are located within 3 miles (5 km) of the DOE property boundary at PGDP. This investigation was undertaken to the North of the PGDP just east of “Patrol Road 2” and north of Ogden Landing Road (KY 358). The site is to the West and Northwest of the closed landfills designated C-746-S and C-746-T and south of the new sanitary landfill, C-746-U.

Figure 1. Location Map for North-South Diversion Ditch Investigation

Early in World War II a 16,126-acre tract of land agricultural land west of Paducah, Kentucky was assembled for construction of the Kentucky Ordnance Works (KOW). In 1950 the Atomic Energy Commission approved the “Paducah Site” for uranium enrichment operations and requested the transfer of the KOW site to the Commission. Construction of PGDP was completed in 1954, but production of enriched uranium began in 1952. With substantial upgrading and refurbishment the original facilities are still in operation.

The uranium enrichment plant enriched recycled uranium from 1953 through 1964 and from 1969 through 1976. Paducah received approximately 90,000 metric tons of recycled uranium containing an estimated 328 grams of plutonium, 18.4 kilograms of neptunium and 661 kilograms of technetium-99. Although most of the plutonium and neptunium were separated out during the initial steps of the enrichment process, some of the transuranics and technetium-99 (99 Tc) are believed to have been deposited on internal surfaces of the feed and
other process equipment, with concentrations also being deposited in waste products. The United States Enrichment Corporation (USEC) has operated the plant since 1993 under lease, with USEC assuming responsibility for compliance activities directly associated with the uranium enrichment operations and the DOE responsible for decommissioning, legacy waste, and environmental restoration activities.

The PGDP is situated in the western part of the Ohio River basin. The confluence the Ohio River with the Mississippi River is about 35 miles (56 km) downstream. The plant is located on a local drainage divide; surface flow is east-northeast toward Little Bayou Creek and west-northwest toward Big Bayou (referred to on U. S. Geological Survey maps as "Bayou Creek"). Big Bayou Creek is a perennial stream that flows toward the Ohio River along a 9-mile (14-km) course. Little Bayou Creek is an intermittent stream that flows north toward the Ohio River along a 7-mile (11-km) course. The two creeks converge 5 km (3 miles) north of the plant before emptying into the Ohio River.

The North-South Diversion Ditch (NSDD) is an original design structure of the PGDP and is located primarily in the north-central area of the plant (north of the C-400 Cleaning Building) but extends along Patrol Road 2 north of the plant security fence to Outfall 003. The SWMU includes approximately 914 m (3,000 ft) of channel inside the security fence and another 649 m (2,130 ft) of channel north of the fenced perimeter. From Outfall 003 continued through another 1,844 m (6,050 ft) of channel to empty into Little Bayou Creek. The NSDD is a surface channel that was used to transfer effluents from the C-400 Cleaning Building, coal pile runoff, and storm water offsite and is a primary tributary of Little Bayou Creek.

In 1981, associated with activities at the two permitted landfills, the course of the NSDD (Little Bayou Creek tributary) north of Ogden Landing Road was altered to its current location. Now parallel to Patrol Road 2 and angling northeast to meet the original course of the tributary north of the C-746-T landfill it had originally followed the course of the original stream near what is now the permit boundary fence of the C-746-S and C-746-T landfills. The original course of the tributary north of Ogden Landing Road was filled at that time to provide a graded slope from the permitted landfills to the new ditch course. However, the position of the former ditch was located on a recent topographic map dated November 1999.

The material excavated from the new ditch was not adequate to provide the desired grade and

“Interviews with current and former truck drivers and landfill workers indicate that the old North South Diversion Ditch was the site of dumping of material other than earthen materials and brush and trees derived from rerouting the Ditch to be parallel with the road. The interviews indicated that, in addition to the contaminated roofing material unearthed last summer near the south end of the buried portion of the ditch, and similar material visible at the surface in other places, other waste materials were dumped in the stream course. Interviews indicated that between two existing cottonwood trees more roofing was dumped but in addition 50 to 60 barrels with unknown and possibly contaminated contents were dumped. Speculation was advanced that the drums may have contained radioactively contaminated water from the process buildings. Interviews indicated that North of the northernmost of the two trees more roofing was placed and fly ash from the on-site power plant was pushed down hill from the C-746-T industrial landfill area. Interviewers indicated that the unknown liquid contents of drums had commonly been flowed onto the fly ash after it was placed in the landfill before pushing the material downhill to fill the ditch.”

(Comment on background material in the Excavation Work Plan received from Bill Klein, DOJ 11/23/1999).

The current ditch course is lightly contaminated compared to segments closer to the PGDP and north of the landfill area. The sediment samples collected from the buried stream course were found to be contaminated in some of the excavated trenches during this investigation.

**Purpose and Objectives of This Study**

The primary objective of this investigation was to determine the presence and location of a cache of 30 to 60 buried 55-gallon drums that were allegedly dumped at the site. In addition, secondary targets such as buried roofing materials, flashing, metal pins, tar substances, fly ash, and concrete rubble were of concern for this project. As described above, historic information and interviews with individuals associated with suspected dumping activities indicated the possibility of the drum burial within the survey area. Since the alleged time of
burial, fill materials have been placed over the site and graded. It was stated by plant workers that the drums may have been dumped into a pre-existing, north-south diversion ditch (NSDD) prior to the addition of new fill materials. The presence of such dumped materials would confirm the interview information, and if true would indicate un-permitted disposal activity and the presence of contamination in the bed of the Old NSDD that could be a source of contamination of the UCRS and RGA.

**Previous Geophysical Investigation**

A geophysical investigation was conducted in November 1999 by a DOE contractor along suspect sections of the ditch and adjacent areas. EM31 and EM61 data were collected in limited areas, and several metal anomalies were detected in the southern, and southeastern portions of the survey area. Because of existing ground conditions, limited survey area, and instrument limitations, the data was not conclusive. GPR data was not found useful in determining the depth of the observed EM anomalies. No magnetometer data was collected. Based on trenching activities conducted early in January 2000, it became evident that the strongest anomalies detected during this survey were associated with near surface metallic waste, not the alleged group of buried drums that were the target of the survey. After two trenches were dug to what appeared to be the bottom of the former stream course NSDD, the excavation was halted and the geophysical investigation described here was initiated.

**This Study**

The North-South Diversion Ditch investigation area includes a 1400-foot by 700-foot parcel to the west and north of the closed C-746-S and C-746-T landfills, and sections within the landfill exclusion zone fence, Figure 2. The investigation was conducted in two phases. The Phase I field activities for this investigation were completed in late January 2000, and the Phase II field activities were completed in mid-May of that year. The results of these investigations combined with historical data and the results of interviews with former site workers were used to locate two primary sites to trench. This report summarizes the combined results of the January and May investigations, and presents interpretations of our results.

The first phase of this investigation was restricted to the area that was covered in the November, 1999 geophysical survey. The second phase expanded the area to the northeast, outside the permitted landfill exclusion area, and to two areas within the landfill boundary.

To meet the objectives of the investigation, we used magnetic and multi-frequency electromagnetic (EM) geophysical methods because in combination, these techniques provide an excellent means for locating the various targets described above.

The magnetic method was chosen because it is very sensitive to the presence of buried ferrous metals such as 55-gallon drums, and it provides an indication of the mass of buried metal at depth. The multi-frequency EM system was used to confirm the results of the magnetic data, and to locate any non-ferrous metal that may exist in the subsurface. These methods act as discriminators between ferrous metals such as steel drums, and non-ferrous metals such as the wastes described above. In addition, the EM system was used to detect lateral and vertical variations in soil conductivity that were associated with the NSDD and variations in fill characteristics.

This data was supplemented by limited low-frequency ground-penetrating radar (GPR) profiling to constrain the depths of the observed EM and magnetic anomalies. Typically, the GPR data allowed identification of objects to depths less than 10 feet, given site soil conditions.
Figure 2. Total Magnetic Field Contour Map
FIELD METHODS

Electromagnetic Method

The electromagnetic (EM) method uses the principle of electromagnetic induction to measure the variability of electrical conductivity of subsurface materials. Significant contrasts in the electrical properties between non-indigenous materials and surrounding soil enable accurate delineation of buried structures and materials. The large EM response to metal (i.e., buried drums) makes this technique particularly well suited to identifying buried metal objects. However, it is equally sensitive to metal objects on the ground surface such as fences, monitoring wells, metal storage bins, and pipelines, and care is required to note those station points where surface metal objects may be influencing the EM measurement to avoid misinterpretation.

A GEM-300 electromagnetic conductivity unit by Geophysical Survey Systems, Inc. was used to collect the EM data. The GEM instrument is a multi-frequency electromagnetic system that can generate EM signals to depths of approximately 40 feet or greater in the subsurface. Four frequencies were recorded at each station point for this survey to obtain data at varying depth ranges in the subsurface. We recorded data at 3,030 Hz, 5,070 Hz, 8,430 Hz, and 14,010 Hz. Typically, the lower frequency signals are transmitted deeper in the subsurface, and the higher frequency signals penetrate the shallower depth ranges. The range recorded covers depths greater than those normally sensed by the EM31 and EM61 instruments most commonly used in this type of investigation. The GEM300 allowed deeper penetration, and better depth profiling, all in a single pass with the instrument.

Both in-phase and quadrature components were recorded at each station point. The in-phase response is very sensitive to the presence of metal objects in the vicinity of the measuring point. The quadrature component provides an indication of the relative conductivity of the soils and materials near the measure point. Typically, both components will exhibit large deviations from background in the presence of metal objects. As the volume of metal increases, and as the target depths decrease, the greater the response from the EM instrument. Both components were used in this study to differentiate buried targets.

Magnetic Method

A model G-858 magnetometer by Geometrics, Inc. was used to conduct the magnetic survey. The total magnetic field measurement was collected with the instrument 1 meter above the ground surface on a 10-foot by 5-foot grid.

The instrument responds to the presence of ferrous metal objects in the vicinity of the measuring station. The prevailing magnetic field is distorted in the presence of ferrous metal objects such as buried 55-gallon drums, metal debris, and buried metal structures. The instrument measures the total magnetic field and the resulting contour plots and magnetic profiles show the locations and three-dimensional extent of buried metal objects. These plots can also be used to derive the approximate volume of metal present within a particular area. Approximate target depths may be estimated by applying graphical solutions to magnetic profiles. In addition, we combined this data with the EM data described above to confirm depth estimates for proposed excavation activities.

Ground-Penetrating Radar

The ground-penetrating radar (GPR) method was used to provide subsurface imaging information over the significant magnetic and EM anomalies. The GPR method is based upon the transmission of repetitive, radio-frequency electromagnetic pulses into the subsurface. The system records a continuous image of the subsurface by plotting two-way travel time of the reflected EM pulse versus distance traveled along the ground surface. Two-way travel time values are then converted to depth
using known soil velocity functions.

A Geophysical Survey Systems SIR System 2 and a 200 megahertz (MHz) antenna were used with a recording window of 80 nanoseconds (ns) to provide the required depth penetration and subsurface detail. The system was optimized to achieve the maximum depth of penetration for the local soil conditions. This depth was approximately 8 to 10 feet below ground surface. For the major anomalies identified in the EM and magnetometer surveys, the GPR data allowed us to determine that the anomalies were deeper than about 10 feet, the estimated maximum depth of penetration of the GPR unit at the site.

**Survey Grid**

In the Phase I investigation, survey grid was established within a 1320-foot by 640-foot area that was bounded by the current course of the NSDD to the West and North, the landfill access road to the South, and the closed C-746-S residential landfill to the east. Permit boundary fence line was used as the primary permanent marker for this grid. Magnetic and EM data was acquired at a 10-foot line interval and 5-foot station interval in the southern half of the survey area, and a 20-foot line interval and 5-foot station interval in the northern half of the survey area. For reference purposes, we placed wooden stakes, flagging tape, and pin flags to mark the locations and extents of certain grid lines along the ground surface (at 50-foot or 100-foot intervals). These markers were left in place to facilitate re-occupation of station points for excavation activities, as needed. A good reference location is station (-100N, 200E), which is located at the southernmost bend in the fence line. The fence post at that point was spray painted and acted as a reference for all the surveys and for locating the excavation sites. Other marker points on the grid, such as monitoring wells and other fence corners provided control over the entire grid.

The Phase II investigation involved the collection of geophysical data over the most pronounced anomalies observed in the Phase I effort. Typically, magnetic and EM data were collected at 5-foot line intervals and 5-foot station intervals to increase the lateral definition of observed anomalies. EM data was obtained for an area that was not covered by EM data during the first phase was survey because the EM instrument failed and GPR data was collected for two of the major anomalies that had been identified at that time. Additional suspect areas were also covered inside the landfill fence and south to Ogden Landing Road (KY 385).

**Geophysical Characteristics of Buried Drums**

Buried drums typically produce very strong EM and magnetic signals. They are electrically-conductive and magnetically-permeable targets, which is ideal for detection with appropriate EM and magnetic systems. Physically, a single 55-gallon metal drum is approximately 3 feet high, 2 feet in diameter, and is composed of 33 pounds of metal. The strength of the EM and magnetic responses is due to (a) the proximity of the measuring station to the drum, (b) the depth of the drum, (c) the orientation of the drum, (d) the physical condition of the drum (new, corroded, crushed), (e) the relative electrical and magnetic character of the drum (conductivity, magnetic permeability), (f) the field topography, and (g) the presence of additional drums or metallic materials near the survey point.

Typically, EM in-phase anomalies are strongly negative over a magnetically-permeable target such as a drum, especially at low frequencies. On the other hand, conductive targets typically exhibit a strong, positive response over a conductive, but not magnetically-permeable target. Often, the EM response is a monopole, where the closed contour lines are directly over the anomaly. An example of this response is shown at station (-160, 155) on the quadrature and in-phase maps in Figures 3 and 4.

The quadrature measurements (Figure 3) are sensitive to changes in soil conductivity and the presence of buried metal objects. The highest quadrature responses are due to buried metal objects (ferrous and non-ferrous). A linear anomaly can be seen approximately 75 feet from the fence line that indicated
the presence of the NSDD. Many small magnetic anomalies were coincident with this anomaly, which suggests that metal objects were dumped there before or during filling the old ditch.

The in-phase map (Figure 4) is sensitive to buried metal objects. By combining the EM in-phase result with the magnetic data it is possible to discriminate between ferrous and non-ferrous buried objects. Many of the magnetic anomalies are also found on the EM map. An interesting contour pattern was observed on the EM in-phase map that may suggest the movement of fluids in the subsurface downgradient from one of the landfill cells.

Another complicating factor that must be recognized, particularly in the area of the radiation controlled zones, is the presence of what appears to be a more or less continuous, although not necessarily homogeneous layer of scrap metal at about 2 to 4 feet below ground surface (bgs). This layer acts as a sort of filter for any signals that might be present from below, screening any drums from the induced signal of the EM system and diffusing any effect on total magnetic field that might be the result of drums at depth. The result is the possibility that a cache of drums that might provide a relatively strong clear signal may not produce a signal or may produce a diffuse signal.

The magnetic response over buried ferrous metal is more complicated. In the case of a single metal object or group of closely-spaced metal objects, the magnetic response is a dipole, whereby a strong positive-negative anomaly pair exists. The object is theoretically located along the steep magnetic gradient connecting the positive and negative anomalies associated with the object or objects. An example of this dipole response is shown at Anomaly #3 on Figure 2. A relatively strong positive-negative anomaly pair exists, and the metal objects are located near station (-1060, 345), where the magnetic gradient is the highest.

At a test site at the Geometrics facility (magnetometer manufacturer), a group of five 55-gallon drums (165 pounds) were buried 6 feet deep, and visible magnetic anomalies were detected from greater than 30 feet in all directions from the group. A group of 30-60 drums, weighing approximately 1000-2000 pounds, and covering an assumed lateral distance of between 10-feet by 10-feet, to 25-feet by 25-feet, would produce a significant magnetic signal, over a radial distance of greater than 100 feet from the center of the source. This response depends on the depth of burial, the way the drums were buried (in a vertically-oriented hole, along the drainage ditch, or randomly scattered over a large area), the cumulative resultant magnetic field of all the drums and surrounding metal debris if present, and the presence of surface noise (metal objects). Decomposition of the drums will reduce the effect on the magnetic field.

As illustrated in Figure 2, the total magnetic field data was contoured and 10 anomalies were defined that implied the presence of buried ferrous metal (Anomaly #8 was removed from the list and the anomalies were not renumbered). In addition, several anomalies were attributable to monitoring wells, exposed pipelines, metal fence lines, culverts, an air monitoring system, and miscellaneous metal objects at the surface. One anomaly was, for example, correlated to a crushed drum at the surface. Anomalies #2 and #10 covered the largest areas and had the highest magnitudes and were the primary targets. Anomaly # 9 was also strong and because it was the closest to the alleged position of the drum cache it was also excavated.
Figure 3. EM 8,340 Hz, Quadrature Contour Map
Figure 4. EM 8,340 Hz In-Phase Contour Map
RESULTS AND DISCUSSION

There were several geophysical anomalies that were observed on the contour plots that indicated the presence of buried metal. The sizes, shapes, and magnitudes of the anomalies varied considerably, but given the anticipated size of the primary target of the investigation, only the most prominent anomalies were considered as potential caches of 30 to 60 buried drums. Although several, small, discrete anomalies and anomalous areas were discovered, they did not exhibit the anticipated response magnitudes and lateral extent to warrant inclusion as a potential cache of drums. Also, the data indicated that many of the largest anomalies were immediately traceable to a known surface object such as a monitoring well, metal fencing, or partially exposed pipeline.

Discussion of Anomalies

Nine anomalies or anomalous areas were defined during the surveys. Their positions and approximate outline are presented on the contour maps included in the main body of the report.

Anomaly #1 is located in the northeast portion of the survey area. This is a moderately strong magnetic anomaly that is centered at station (-1200N, 560N, in Figure 1). It exhibits a magnetic dipole anomaly signature and covers an area of 40 feet by 70 feet. The anomaly exhibits a peak-to-peak magnitude of approximately 350 nT, and an approximate depth of 15 feet bgs. Based on the data, the depth computations here are approximately +/-3 feet. The eastern part of this anomaly is partially affected by the metal fence. Theoretically, the metal objects associated with this anomaly are located at about the center point station. The EM data indicated weak responses and did not support the presence of buried drums.

Anomaly #2 is located along the fence line approximately 150 feet to the southwest of Anomaly #1. It is approximately 120 feet long by 60 feet wide, and extends through the fence line to the magnetic profile area. Figure 2 shows the magnetic results to the northwest of the landfill, and on the landfill side of the fence line. The outline of the anomaly was refined somewhat during the Phase II survey. Anomaly #2 is the largest anomaly in aerial extent, and possesses the largest magnetic and EM deflections of any of the surveyed areas. For this reason, Anomaly #2 was considered significant mass of buried ferrous metal. The anomaly is centered at station (-1120N, 590E), and the magnetic profile indicates a depth of burial of approximately 9 feet bgs, graphically defined using the half-width rule. Depth computations are +/-5 feet here due to effects from the metal fence defining the “T” landfill boundary. The GPR data indicated the presence of a few, shallow (0-4 feet), metal anomalies in the subsurface. Based on all of the data collected here, we believed that more buried metal existed below 4 feet. EM data also indicated the possibility of a buried seep that is oriented from east to west. A band of decreased in-phase EM responses was observed along line -1150.

Anomaly #2 was considered a target although it was far from the site of the alleged drum dumping activities because it was located in an area where the disposal of fly ash and liquid contents of drums that were then crushed and left in place had been alleged. The trenching activities unearthed a buried pile of metal fencing that was approximately 3-6 feet bgs. The GPR data indicated anomalies within the upper 6 feet or so, and the magnetic depth computations indicated the anomaly was approximately 10 feet bgs. The bottom of the trench at about 12 to 14 feet was described as “very moist to wet”, in late-August, and the presence of rootlets and rusty red clay “indicated the old ground surface had been encountered. No contamination was detected in samples from just above the bottom of the trench.

Anomaly #3 is similar to Anomaly #1 in that it is moderately strong in magnitude, and possesses a strong dipolar character. The center of the outlined area, station (-1060N, 340E) is considered the location of buried ferrous metal targets. The anomaly is approximately 70 feet long by 25 feet wide and approximately 10-15 feet deep. It was not considered to be a potential drum burial area.

Anomaly #4 is present on the magnetic contour plot. The anomaly is very close to monitoring well MW17, and the data suggests strongly that the well is the sole source for the anomalous magnetic
response. For this reason, Anomaly #4 was not considered for excavation.

Anomaly #5 is located to the southwest of Anomaly #4 by 150 feet. The approximate dimensions of the anomaly are 50 feet long by 40 feet wide, and it is oriented in a northwest-to-southeast direction. Due to the relatively small lateral extent of the anomaly and the low magnitude signals, this anomaly is not considered to be a large cache of drums.

Anomaly #6 is located along the fence line near station (-760N, 210E). Very strong, positive magnetic signatures are present, and the contour data suggests that the source may be a monopole. The anomalies are very close to monitoring wells MW40 and MW39, and this type magnetic response is characteristic of monitoring wells.

Anomaly #7 is located 200 feet to the east of Anomaly #6. It is within the landfill permit limits and covers an area of approximately 90 feet (east-west direction) by 40 feet (north-south direction). The peak-to-peak magnitude is approximately 300 nT which indicates the presence of buried ferrous metal. Since Anomaly #7 is so close to the landfill cell C746-T, the source of the anomaly may be miscellaneous ferrous waste from the cell.

Anomaly #9 covers a broad area around the two rad areas. The magnetic responses here indicate slightly decreased total field values surrounding the rad zones. The data included in the Phase II investigation was collected after the chain link fences and support poles were removed. The data quality was significantly improved, and the interpretation more easily completed. The initial geophysical investigation results and subsequent trenching activities indicated the presence of a large amount of buried metal debris. Given the advantage of having an existing geophysical data set, two trenches at anomaly locations identified in the original survey and our detailed EM and magnetic data sets, it appears that the anomalies are related to a broad area of buried waste materials. Within the Anomaly #9 limits however, there are no strong magnetic responses above or below the average Anomaly #9 magnetic responses that would suggest the presence of a large cache of buried drums. The data suggests that buried metals are randomly distributed within the Anomaly #9 limits. The in-phase EM data shows distinct anomalies to the north of the northern rad area and to the southeast of the central rad area. Elevated in-phase responses are observed between these rad areas, as well. Trenching one of the southeast sub-anomalies confirmed the geophysical results revealing metal waste, one 4 foot by 4 foot metal sheet for example and roofing material including steel and copper flashing.

Anomaly #10 is located around the southern rad area. During our initial survey, a very strong monopole signal was present to the south of the rad area on the magnetic contour plot. Its signature was very similar to those observed at several monitoring well locations, such as MW40, MW39, and MW346. However, good records exist for the location of wells and borings for PGDP and there was no indication of a well or boring there. The site was close to the site where initial excavations for a new monitoring well had exposed rad-containing soil and roofing materials. The rad area was surrounded by magenta and yellow chains and sheet aluminum signs hung on steel posts. Following the removal of the chain and steel posts during the second phase of the investigation, a strong dipole signature was observed at this location. The magnetic data indicated the presence of a significant mass of buried ferrous metal. The in-phase EM data has a subdued character and the GPR data indicated the presence of metal objects within the upper 4 feet of soils. Some of the GPR anomalies were discrete, covering 1-2 feet and others were several feet in length. The source of the strong dipole signature could not be determined from the GPR data due to the limited penetration (approximately 6 feet) indicating that the source is deeper than 6 feet.

Anomaly #10 was trenched first because it was close to the alleged barrel dumping. It was almost directly on the course of the old NSDD and near the entrance of the landfill at the time of the alleged dumping. The magnetic anomaly possesses the second highest magnitude in the survey area, and is above the magnitude expected from areas where roofing material and metallic flashing was known based on earlier trenching to have caused small magnetic anomalies. The GPR data confirmed that the
depth to Anomaly #10 was greater than 6 feet. No large, discrete, targets were observed on the GPR profiles collected directly over the anomaly. The subsequent trenching activities unearthed a 15-foot long steel railroad and other ferrous metal objects at a depth of approximately 9 feet bgs; however, no drums were discovered here, and in-situ soil was encountered at a depth of 16 feet.

OTHER OBSERVATIONS

Original Stream Course

The EM quadrature data indicated the presence of the historic, north-to-south drainage ditch on the contour plots. It is characterized by elevated quadrature responses related to soil conductivity and a linear to sublinear geometry, as shown in Figure 3. These locations are coincident with the ditch locations described in a previous report. The approximate trend of the ditch includes stations (0N, 170E), (-80N, 140E), (-180N, 130E), (-320N, 135E), (-450N, 140E), (-650N, 135E), (-750N, 125E), and (-880N, 200E). Historic information has shown the ditch continues to the northeast along the fence line, approximately 50-100 feet from the fence. With this information, it appears that magnetic anomalies #1, #2, #3, and #5 are within the suspected trend of the drainage ditch, or very close to it (Figure 2). The EM data indicated that the trench is approximately 15 feet bgs along its length. The strongest drainage ditch signals were observed on the 8,430 Hz and 14,010 Hz quadrature data sets, which cover this general depth range. The magnetic data shows several small-scale anomalies along the ditch, as well.

Possible Evidence of Leaking Landfill

The in-phase contour data to the west of the fence between lines -250N and -600N indicate a series of linear bands that run from the east to the west, as shown in Figure 4. These bands may be related to fluids emanating from the landfill or from concentrated lateral drainage of infiltrated precipitators. The EM contour lines are all normal to the topographic trends in the area, which suggests that the flow direction is down gradient to the west. It appears that gravity drainage is taking place here. These drainage patterns are more visible on the quadrature plots from the 3,030 Hz, 5,070 Hz, and 8,430 Hz data sets than the 14,010 Hz data set, thus suggesting that the primary drainage is taking place below approximately 15 feet. The area between lines -375N and -600N exhibits the most concentrated movement of fluids.

SUMMARY AND CONCLUSIONS

The combination of geophysical techniques used for the North-South Diversion Ditch investigation was effective in locating targets for intrusive investigation. Ten anomalies were identified that represented metallic deposits at depth. The combination allowed winnowing that set of targets to just two that were potentially steel drums, buried in the old waterway or deposited in or along the ditch as the “T” landfill was constructed. The methods used and the use of a close spaced grid for sampling of magnetic and EM data provided high quality and detailed data, closely locating the anomalies.

These techniques also provided information that allowed, combined with site knowledge, screening of targets. At least one such anomaly was attributable to a decommissioned monitoring well and other anomalies required removal of exclusionary fencing (chains and metal posts) to allow clear definition of the underlying anomaly. The use of multi-frequency EM and low frequency GPR helped localize the anomalies vertically, recognizing the limitations of each technique. The GPR was limited to depths of about six to ten feet and the EM and magnetic data was at times confounded by near surface dispersed metallic chaff in the form of metallic roofing materials as observed in the Anomaly #9 area. At Anomaly #2, the GPR correctly identified objects near the surface but at Anomaly #10, nothing was identified within the effective range of the GPR, indicating that the cause of the anomaly was at a depth greater than 6 feet. The ability to closely locate and information on depth to the source of the anomaly based on the combined data sets allowed efficient planning for excavation.
Finally, while it is possible that drums were disposed of in or along the waterway, it is unlikely, based on this investigation and on the subsequent trenching activities that they were deposited as described by the allegers. If drums were deposited in the quantity that was alleged, they either have decomposed or were spread out along the length of the NSDD. No magnetic or EM signature large enough to be a compact pile of 30 to 60 drums was detected along the course of the ditch. If the ditch is determined to be a significant hazard and is excavated in whole or in large part, the indisputable answer to our question may be had. In the meantime, the presence of one lone barrel at the surface near Anomaly #10 provides a haunting reminder of the original question.